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ASSESSMENT OF MARINE AUXILIARY ENGINES LOAD FACTOR IN PORTS

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Abstract:
For the calculation of emission of air pollutants generated by ships in port it is needed, besides other things, knowledge of the load factor of marine auxiliary engines. The value of this factor in the reports of global organizations, dealing with air pollutants emission from ships, is determined mainly on interviews with chief engineers on board. The paper presents the method of assessment of this factor based on identification tests of marine electric power systems carried out by the authors. The obtained in this way results are compared with the values given in the global organizations reports.

Key words: *air pollutants emissions from ships in ports, auxiliary engines load factor*

INTRODUCTION

The load factor of marine auxiliary engines is one of the basic information for the calculation of air pollutants emission generated by ships. The load factors for different types of ships, determining the results of emission calculations, are provided in various reports with greater or less approximation.

For auxiliary engines, reports of the world's organizations, dealing with air pollutants emissions, present statements of load factors depending on the type of vessel and operating conditions [1, 2, 3]. These statements are prepared on the basis of data collected from registers of ships, log book records and interviews with captains of ships, chief engineers and officers of pilot stations.

Table 1 provides a summary of auxiliary engines to the main engine power ratios and auxiliary engine load factors in port – hoteling mode (based on the [2]).

Determined in such a manner auxiliary engines load factors are not very precise. This is mainly due to the lack of empirical data on real operating load values of marine electric power systems [4]. The data in the various types of reports sent periodically by chief engineers to ship owning companies technical services, supervising the operation of ships, are too residual, as the authors wrote in the paper [5]. In addition, the load of marine generating sets read from power meters built in Main Switch Board (MSB) or marine power plant alarm system control panel in Engine Control Room (ECR) is not equivalent to the load of auxiliary engines. The load of auxiliary engine must be calculated taking into account the engine excess power factor to generator and the efficiency of generator. Unfortunately, in the case of data collected by the ship classification societies, there is no information on the efficiency of generators, the auxiliary engines excess power factors to generators or auxiliary engines continuous power, but only a nominal value of generating sets active power, understood as the active power of generators. Therefore, auxiliary engines load factors given in table 1 corresponds more to the load factor of generating sets (generators).

Therefore, the authors developed a method for determining the load factors of marine auxiliary engines in ports in hoteling mode for different types of ships based on identification tests of marine electric power systems load. Description of the method and the results are presented below.

Table 1
Auxiliary engine power ratios and auxiliary engine load factor in port – hoteling mode [2]

Ship Type	Average Propulsion Engine (kW)	Average Auxiliary Engines			Auxiliary to Propulsion Ratio	Auxiliary Engine Load Factor in port – hoteling mode
		Power Each (kW)	Total Power (kW)	Engine Speed		
Auto Carrier	10700	983	2850	Medium	0.266	**0.24**
Bulk Carrier	8000	612	1776	Medium	0.222	**0.22**
Container Ship	30900	1.889	6800	Medium	0.220	**0.17**
Passenger Ship	39600	2.340	11000	Medium	0.278	**0.64**
General Cargo	9300	612	1776	Medium	0.191	**0.22**
Miscellaneous	6250	580	1.680	Medium	0.269	**0.22**
RORO	11000	983	2850	Medium	0.259	**0.30**
Reefer	9600	975	3900	Medium	0.406	**0.34**
Tanker	9400	735	1985	Medium	0.211	**0.67**

Therefore, the authors developed a method for determining the load factors of marine auxiliary engines in ports in hoteling mode for different types of ships based on identification tests of marine electric power systems load. Description of the method and the results are presented below.

IDENTIFICATION TESTS OF MARINE ELECTRIC POWER SYSTEMS LOAD

The reasons for undertaking the identification test of marine electric power systems load and the problems arising from their conduct were widely described by authors in [4]. In connection with the implementation of the international project: *BSR InnoShip: Baltic Sea Cooperation for Reducing Emissions ship and port through knowledge and innovation* in the Maritime University of Szczecin, there was a need to use the results of identification tests of marine electric power systems load to determine the empirical load factor of marine auxiliary engines.

In the Maritime University of Szczecin the identification tests of marine electric power systems *(MEPS)* load were carried out on various types of transport vessels operating by foreign and domestic ship-owners. The study were conducted in the years 2002-2007, registering the load of *MEPS* in all typical operating states for a given ship and in different conditions of climate and weather. There were analyzed 14 types of vessels, that had sister units, built in the years 1977-2005: three of them in the years 1977-1980, two in the years 1980-1990, four in the period from 1990 to 2000 and five after 2000. Ships built before 1977 and covered by identification tests of marine electric power systems load were not included in the analysis, although they are currently still in operation, assuming that the age of the ship may not exceed 30 years. The vessels were built in shipyards in Bulgaria, China, France, Japan, Yugoslavia, South Korea, Germany, Norway, Poland and Taiwan.

14 types of vessels includes six various size container ships (7500 TEU-1100 TEU), two types of semicontainer ships, three types of bulk carriers and one type of general cargo vessel, tanker DP2 and chemical tanker. Total length of the vessels ranges from 72 m to 300 m. Power rating of main engines ranges from 1 470 kW to 69 440 kW. As the main propulsion unit on ten types of vessels was used a low -speed engine and a medium speed engine on remaining four vessels. As a propeller in ten cases was used fixed screw propeller and in the other cases control pitch propeller. Direct drive of propeller was used on nine types of ships and indirect drive on the other five (four geared-down drives and one hydrodynamic coupling). In addition, one of the vessels was equipped in emergency propulsion by using shaft generator as an electric motor.

Eleven ships were equipped with thrusters. In most cases (nine ships) there was installed a single bow thruster. Only on two types of vessels (one of the container ships and tanker DP2) there were bow and stern thrusters. On ten ships the thrusters drive was realized by means of electric motor. In one case the thruster was equipped with hydraulic drive.

Some of the analyzed types of ships were equipped with cargo handling equipment, allowing the handling of cargo at ports without an adequate technological background.

Continuous recording of changes in *MEPS* load on vessels not equipped with modern computer systems aided marine power plant operation is impossible. Often, even if such a system exists, access to the data recorded is limited. On older systems not equipped with hard drives, like *HMS 3000*, the current load value is displayed on the control panel, but is not stored in system memory. Systems with built-in hard drives do not allow an ordinary user – an engineer – to copy data directly from hard drive to removable media, but they required for this operation registered password of system serviceman. Due to the fact that at the same time, the system records a number of significant parameters in marine power plant operation, even with today's hard drive capacity, hard drive free space is rapidly filling. In practice, to avoid periodic replacement of hard drives, collected data is automatically reset at specified intervals.

For these reasons, it is necessary to simplify *MEPS* load registration. *MEPS* load changes during the established hours can be treated as realizations of the stochastic process and characterized by one specific value – the maximum consumed power during particular hour. The maximum power demand must be realized by generating subsystem of *MEPS*, otherwise a cargo ship will not be able to implement all the tasks. Selecting any other single load value of *MEPS*, registered during considered realizations of the stochastic process (except the minimum value), involves only general information about the changes of power demand, because it should be treated as the current value of the load. However, even the estimation of the average load during the established hour on the basis several or tens current values of the load or knowledge of the minimum and the maximum values of power demand seems to be burdened with significant error. This is due to irregular process of load changes for the established hour.

The value of the maximum power demand in *MEPS* occurring in consecutive operating hours is a random variable. Such a definition of the random variable corresponds to the concept of the peak load P_s for a given hour, commonly used in the power industry. Assignment of this random variable to consecutive specified time intervals (established operating hours) is known as the empirical time series [6].

Selection of an hour as a time interval seems to be justified for several practical reasons. First of all, it allows to conduct observations of the load by an Engine Room crew member in a way that does not impede the process of marine power plant operation and is quite comfortable for the observer, especially when it is not possible to use automatic load records due to lack of advanced monitoring system. It also allows to track and present the dynamics of the load changes during the following hours of observation and enables assignment of consecutive operating hours to the respective occurred operating states, that have the greatest impact on the load of *MEPS*. In the steady operating states, during the sea voyage, mooring at a port without a usage of marine handling equipment, drift, or stop at the anchorage, the load of *MEPS* does not change dramatically in the following hours, as opposed to dynamic operating states, when the rapid changes in the load take place due to usage of thrusters or ship-handling equipment and switching on the other large power receivers.

The presentation of the peak loads of *MEPS* in the form of the empirical time series requires a usage of several simplifications. It should be assigned to any given hour of observation a specified operating state corresponding to the

observed peak load. Therefore, it is necessary to round the duration of the vessel operating states to the full hours. Due to the fact, that the time limits of operating states are in practice contractual, it does not cause large errors, especially if usually the period of observation of *MEPS* loads lasts a few months and the number of hours varies from several hundred to several thousand.

Moreover, when considering the empirical time series, it is impossible to give precise moments of switching on and off generating sets or shaft generators from the main bus bars of *MSB*. Thus, there is also a need to round their operating time to the full hours.

The adopted methodology does not allow to analyze the dynamic phenomena occurring in *MEPS* during the synchronization of generators and load-sharing between generating sets in the parallel operating mode.

For the measurements of the active power, generated by marine electric power station, it was used the measuring apparatus, that was standard equipment of the vessel. It is covered by the supervision of classification societies and meets the imposed requirements. Moreover, in the case of modern ships, it meets the requirements of full redundancy of measurements. The value of the current load of generating sets can be recorded by means of power meters located in *ECR*, local control panels of generating sets and on the bridge.

DETERMINATION OF THE AUXILIARY ENGINES LOAD FACTOR ON THE BASIS OF THE IDENTIFICATION TESTS OF MARINE ELECTRIC POWER SYSTEMS LOAD

The values of particular generating set load, defined as active power measured on the *MSB* bus bars, were given as fractions of the generator rated active power. To determine the auxiliary engine load factor it is necessary to take into account the efficiency of the generator and the auxiliary engine excess power factor to the rated active power of the generator.

When ship stays in port, generally only one generating set is in stand-alone operation. Although in case of cargo handling operation, carried out by means of ship's cargo handling facilities, the parallel operation of at least two generating sets is needed. The empirical distribution of generating sets load, obtained during stand-alone operation in ports, for ships in the study, were presented by means of Box-and-Whisker plots on fig. 1. In the case of vessels with generating sets of different rated active power, fig. 1 shows the distributions for generating sets of higher rated output (*GS HRO*), and fig. 2 shows the distributions for generating sets of lower rated output (*GS LRO*).

Due to the illustration of the achieved loads distributions of the generating sets by means of Box-and-Whisker plot introduced by Tukey in 1979 it is easy to compare their measures of location, dispersion and asymmetry, that is their minimal and maximal values, median and the upper and lower quartiles. The diversity of values of the peak load of the generating sets is estimated by means of comparing the length of four consecutive segments defining 25% of the registered peak load value. The variety of 50% of the most typical load values is proved by the box height of the plot adequate to the inter-quartile range. But asymmetry of the whole distribution is evaluated by comparing so called whiskers. If the upper whisker is longer than the bottom one the distribution is characterized by the right-hand side asymmetry and analogically, if the bottom whisker is longer than the upper one the distribution has left-hand side asymmetry. Asymmetry among 50% of the most typical peak load values is assessed due to the analysis of median location. If the median is closer to the upper (third) quartile, represented by the upper side of the Box-and-Whisker plot the distribution of the peak loads in the middle part is left-hand asymmetric and analogically, if the median is closer to the bottom (first) quartile represented by the bottom side of the Box-and-Whisker plot the distribution of the peak loads in the middle part is right-hand asymmetric.

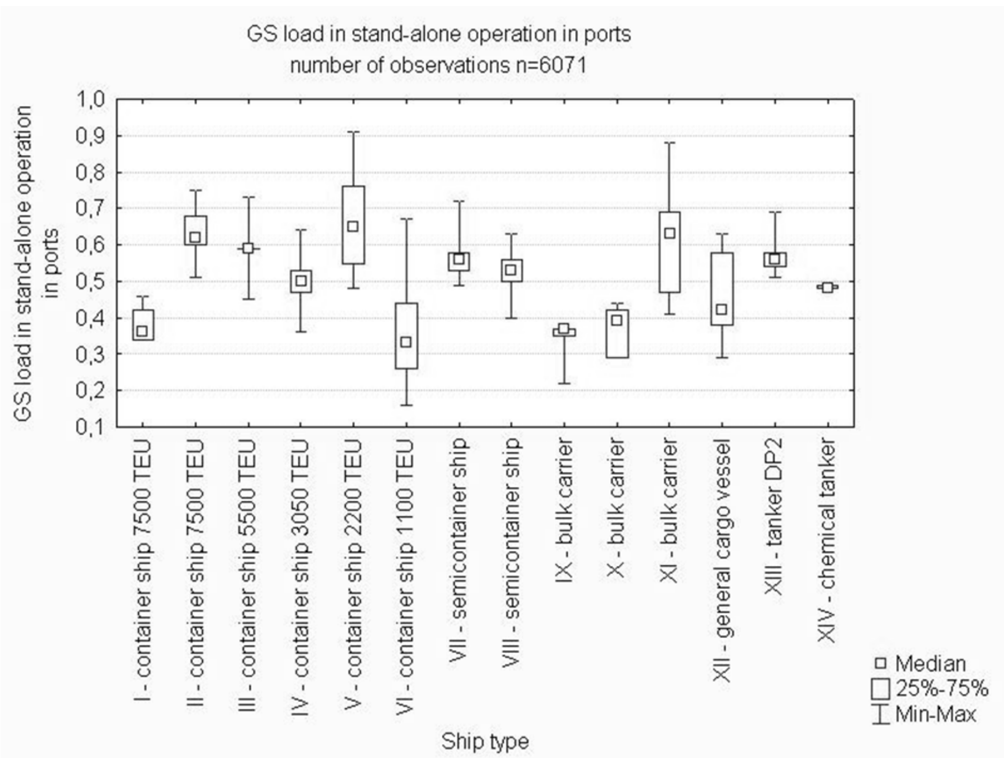

Fig. 1. The empirical distributions of generating sets load, obtained during stand-alone operation in ports for various types of ships, presented by means of Box-and-Whisker plots

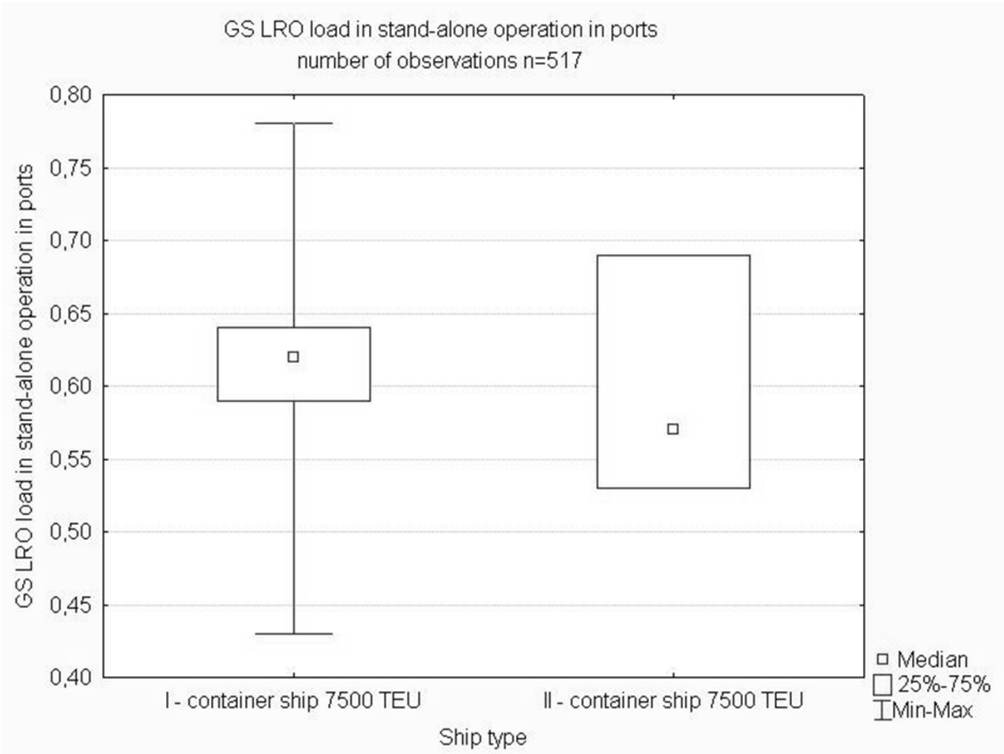

Fig. 2. The empirical distributions of generating sets of lower rated output load, obtained during stand-alone operation in ports, presented by means of Box-and-Whisker plots

The empirical distributions of generating sets peak load, presented in fig. 1 and 2, were the basis for the analysis of auxiliary engines load, discussed later in this work.

The statistics of generating sets load distributions are presented in table 2, and the statistics for generating sets of lower rated output are presented in table 3.

Generating subsystems of MEPS on ships in the study differ significantly in auxiliary engine excess power to rated active power of generator. Auxiliary engine excess power factor to generator (αNM) ranges from 1.05 to 1.62. The lowest values of the factor were recorded in ships built after 2000. A detailed listing of the values of the factor were summarized in table 4. In case of ships, where more than one type of generating set was installed, respectively more than one value of the factor was given in table 4.

Table 2
The statistics of generating sets load distributions obtained for stand-alone operation in ports

Ship type	Generating set load in stand-alone operation in ports							
	mean	median	standard deviation	minimum	maximum	_25%	_75%	number of observations
I	0.372571429	0.36	0.037851648	0.34	0.46	0.34	0.42	105
II	0.628958785	0.62	0.0594814589	0.51	0.75	0.6	0.68	461
III	0.589751381	0.59	0.0593472719	0.45	0.73	0.59	0.59	362
IV	0.496153846	0.5	0.0678894274	0.36	0.64	0.47	0.53	13
V	0.657597403	0.65	0.118476468	0.48	0.91	0.55	0.76	154
VI	0.352734478	0.33	0.124891352	0.16	0.67	0.26	0.44	2271
VII	0.559751037	0.56	0.0481795348	0.49	0.72	0.53	0.58	723
VIII	0.534683794	0.53	0.0451268708	0.4	0.63	0.5	0.56	506
IX	0.360070671	0.37	0.0241308077	0.22	0.37	0.35	0.37	566
X	0.368217822	0.39	0.0558103223	0.29	0.44	0.29	0.42	101
XI	0.60587013	0.63	0.134031378	0.41	0.88	0.47	0.69	385
XII	0.433043478	0.42	0.114816206	0.29	0.63	0.38	0.58	115
XIII	0.570275862	0.56	0.0449674212	0.51	0.69	0.54	0.58	290
XIV	0.484736842	0.48	0.00512989176	0.48	0.49	0.48	0.49	19

Table 3
The statistics of generating sets load distributions obtained for stand-alone operation in ports (for generating sets of lower rated output – GS LRO)

Ship type	Generating set load in stand-alone operation in ports – GS LRO							
	mean	median	standard deviation	minimum	maximum	_25%	_75%	number of observations
I	0.604823944	0.62	0.075277841	0.43	0.78	0.59	0.64	284
II	0.594034335	0.57	0.0676644779	0.53	0.69	0.53	0.69	233

In order to determine the auxiliary engine load factor, it is necessary to take into account the efficiency of the generator and the auxiliary engine excess power factor to rated active power of the generator in the individual generating set. This requires the knowledge of the technical data of auxiliary engines and generators in generating sets. Assuming the efficiency of generators η_G=0,95 [7], auxiliary engine load factor is given by formula:

$$LF_{AE} = \frac{LF_{GS}}{\eta_G \cdot \alpha_{NM}} \quad (1)$$

where:
LF_{AE} – load factor of auxiliary engine,
LF_{GS} – load factor of generating set (generator),
η_G – efficiency of generator (0,95),
α_{NM} – auxiliary engine excess power factor to generator.

As the load factor of the generating set (generator) LFGS was proposed the value of mean or median presented in table 2 and 3. By using the formula (1) auxiliary engine load factor can be now calculated. Calculated in that way the empirical values of the auxiliary engine load factor were presented in table 5 and 6.

Table 4
Auxiliary engine excess power factor (α_{NM}) to active power of generator in generating sets on ships covered by identification tests of MEPS load

Ship type	Year of built	Auxiliary engine excess power factor to generator
I - container ship 7500 TEU	2004	1.05 1.05
II - container ship 7500 TEU	2005	1.05 1.05
III - container ship 5500 TEU	1999	1.40
IV - container ship 3050 TEU	2001	1.05
V - container ship 2200 TEU	2003	1.06
VI - container ship 1100 TEU	1982	1.21
VII - semicontainer ship	1986	1.62
VIII - semicontainer ship	1979	1.25
IX - bulk carrier	1993	1.60
X - bulk carrier	2003	1.10
XI - bulk carrier	2000	1.09
XII - general cargo vessel	1979	1.46
XIII - tanker DP2	1993	1.07
XIV - chemical tanker	1979	1.11 1.26

Table 5
Auxiliary engine load factor in port on ships covered by identification tests of MEPS load

	Auxiliary engine load factor in port – LF_{AE}	
Ship type	mean	median
I - container ship 7500 TEU	0.374	0.361
II - container ship 7500 TEU	0.631	0.622
III - container ship 5500 TEU	0.443	0.444
IV - container ship 3050 TEU	0.497	0.501
V - container ship 2200 TEU	0.653	0.645
VI - container ship 1100 TEU	0.307	0.287
VII - semicontainer ship	0.364	0.364
VIII - semicontainer ship	0.450	0.446
IX - bulk carrier	0.237	0.243
X - bulk carrier	0.352	0.373
XI - bulk carrier	0.585	0.608
XII - general cargo vessel	0.312	0.303
XIII - tanker DP2	0.561	0.551
XIV - chemical tanker	0.460	0.455

Table 6
Auxiliary engine of lower rated output load factor in port on ships covered by identification tests of MEPS load

	Auxiliary engine of lower rated output load factor in port – LF_{AE}	
Ship type	mean	median
I - container ship 7500 TEU	0.606	0.622
II - container ship 7500 TEU	0.596	0.571

For small values of the auxiliary engine excess power factor α_{NM} (1.05-1.10), i.e. when the diesel engine rated power was fairly well adjusted to the rated active power of generator in generating set and with efficiency of generator at 0.95, it can be assumed that the engine load is equal to the generator load.

If there is a need to express the auxiliary engine load factor in percent of its rated power, then the formula (1) takes the form:

$$LF_{AE} = \frac{LF_{GS}}{\eta_G \cdot \alpha_{NM}} \cdot 100\% \qquad (2)$$

and the values given in tables 5 and 6 must be multiplied by 100.

CONCLUSIONS

Presented in table 5 and 6, the auxiliary engine load factors in port for ships covered by identification tests of marine electric power system load, are higher than the values given in table 1. However, it is necessary to note that the values given in table 1 were analyzed statistically for a big number of similar units, while the data in tables 5 and 6 relate to specific individual ships or sister ships. These factors may be higher due to the usage of the ship's cargo handling equipment in ports, which some of the analyzed ships were equipped with.

The proposed method for determining the auxiliary engines load factors in ports is certainly more reliable than the methods of data collection based on interviews with chief engineers. In the long time perspective, access to data on generating sets load will be facilitated with the use of universal already on board the satellite communications and computer systems for monitoring marine power plant operation, including marine electric power system. With the implementation of the relevant administrative rules, port authorities would automatically receive data from a ship on generating sets load and fuel consumption, while the ship stays in port, and with knowledge of the generators efficiency and the values of auxiliary engines excess power factors to generators, precisely define the actual auxiliary engines load factors and emissions of air pollutants, which are generated.

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